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SVHSER 10630

CR-171940  
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SPACE AND SEA SYSTEMS DEPARTMENT

FINAL REPORT

CONTRACT NAS9-17020

DEVELOPMENT

OF A

PRE-PROTOTYPE POWER ASSISTED GLOVE END EFFECTOR

FOR

EXTRAVEHICULAR ACTIVITY

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

(NASA-CR-171940) DEVELOPMENT OF A  
PRE-PROTOTYPE POWER ASSISTED GLOVE END  
EFFECTOR FOR EXTRAVEHICULAR ACTIVITY Final  
Report (Hamilton Standard, Hartford, Conn.),  
26 p

N87-13989

Unclas

CSCL 05H G3/54 43488

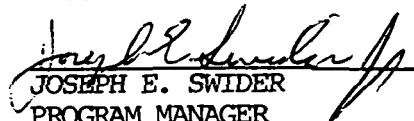
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**I.      INTRODUCTION**

Space Shuttle EVA operations have demonstrated the benefits of utilizing man to conduct various tasks in space (i.e., Missions 41C Solar Max repair, 51A retrieval of PALAPA-B-2 and WESTAR-VI, 51D attempted SYNCOM repair, 51I LEASAT retrieval, repair, and redeployment, and 61B Space structure construction).

Most of the tools to date have been manually operated or have been designed for a specific application and, as a result, cannot be used for a wide variety of EVA tasks.

The development of an EVA power tool that can be used for many different applications offers significant advantages over developing a new tool for each specific need, especially when the need arises on-orbit.

The purpose of this program is to develop an EVA power tool which is capable of performing a variety of functions while at the same time increasing the EVA crewmember's effectiveness by reducing hand fatigue associated with gripping tools through a pressurized EMU glove.



II.

SUMMARY/RECOMMENDATIONS

The PAGE Pre-Prototype hardware met or exceeded all of its technical requirements and has incorporated acoustic feedback to allow the EVA crewmember to monitor motor loading and speed. If this tool is to be developed for flight use, several issues need to be addressed:

- A thermal vacuum test to determine heat generation for various duty cycles which in turn could be used to decide whether or not cooling or overtemperature shutdown would need to be incorporated into a flight version.
- Miniaturization of the motor control electronics using high reliability components or the selection of a brushless motor with integral control electronics needs further study.
- A decision needs to be made as to whether or not EVA tools will be required to use hermetically sealed switches.
- The present glove mounted acoustic pickup would require the development of a suitable connector at the wrist disconnect as well as integration into the EMU communications equipment. The accelerometer contains a preamp which needs a constant current supply of approximately 1.5 mA at 18 VDC. This low power consumption would not impact present battery requirements.

### III. DESIGN GUIDELINES/REQUIREMENTS

There are two sets of requirements for the PAGE pre-prototype tool, those required by contract, and those derived by Hamilton Standard in our study of potential tool usage.

The contractual PAGE tool requirements are as follows:

The power tool must provide:

- Drilling capability
- Torquing at a minimum of 5 Ft.lbs
- Reciprocating motion
- A means for reversing rotation
- Variable speed
- Right or left handed operation
- Adaptability for EVA use
- 500 hour life

The Hamilton Standard derived requirements are as follows:

- Be capable of operating with a 25 lb thrust force
- Torquing speed of 50 RPM
- Drilling speed of 800 RPM
- Reciprocating stroke of 5/8 inch
- Horsepower between 1/10 and 1/8
- 5 hour working time per 7 hour EVA with a 5% duty cycle

#### IV. EVOLUTION OF DESIGN - A REVIEW OF CONCEPTS

##### Glove Concepts

The initial PAGE program effort was focused on the reduction of hand fatigue by equalizing pressure across the EMU glove. This was accomplished by creating a removable housing over the gloved hand which contained the actuating trigger and valving and interlocks required to pressurize the housing. A mockup of this concept appears in Figure 4-1 and a diagram in Figure 4-2. The "canned hand" was large and bulky due to the size of the EMU glove it had to contain. An IVA glove was considered to reduce the housing size, but this would leave the EVA crewmember "one handed" which was considered to be an unacceptable condition from a safety standpoint.

Several other concepts were then investigated which required modifications to the glove. The first, referred to as "Adapted Glove #1" (ref. Figure 4-3 and 4-4) enclosed the index finger in a chamber. Attached to this chamber was an integral handle with a tool mounting interface. The trigger switch was contained in the chamber. A velcro strap was used to hold the gripping fingers around the handle to reduce hand fatigue further. Although this was an improvement over the enclosed hand concept, the permanently mounted handle and index finger chamber proved to be cumbersome when the tool was not needed.

This led to two minor adaptations, the first of which leaves the chamber around the index finger, but utilizes a small mounting bar at the palm in place of the integral handle (ref. Figure 4-5). The tool handle would slide onto the mounting bar and be locked in place and the gripping fingers would be retained by the velcro strap. The second adaptation referred to as "Adapted Glove #2" left the first two fingers in the glove for improved gripping for non-tool usage and placed the last two fingers in a chamber. The trigger switch was again mounted inside the chamber and a mounting bar remained for attachment of the tool handle (ref. Figures 4-7 and 4-8).

A review was held with NASA where it was decided that further development of these concepts was considered "engineering detailing" and not part of the program effort.

The program effort was then shifted to additional human factors studies including the incorporation of acoustic feedback and generic control through glove mounted sensors.

##### Acoustic Feedback Concepts

In an effort to permit the EVA crewmember the capability of hearing motor speed and loading, several concepts were studied. The first was a modified stethoscope mounted in the palm which transmitted acoustic vibrations through an air line. Several issues which were not addressed included:

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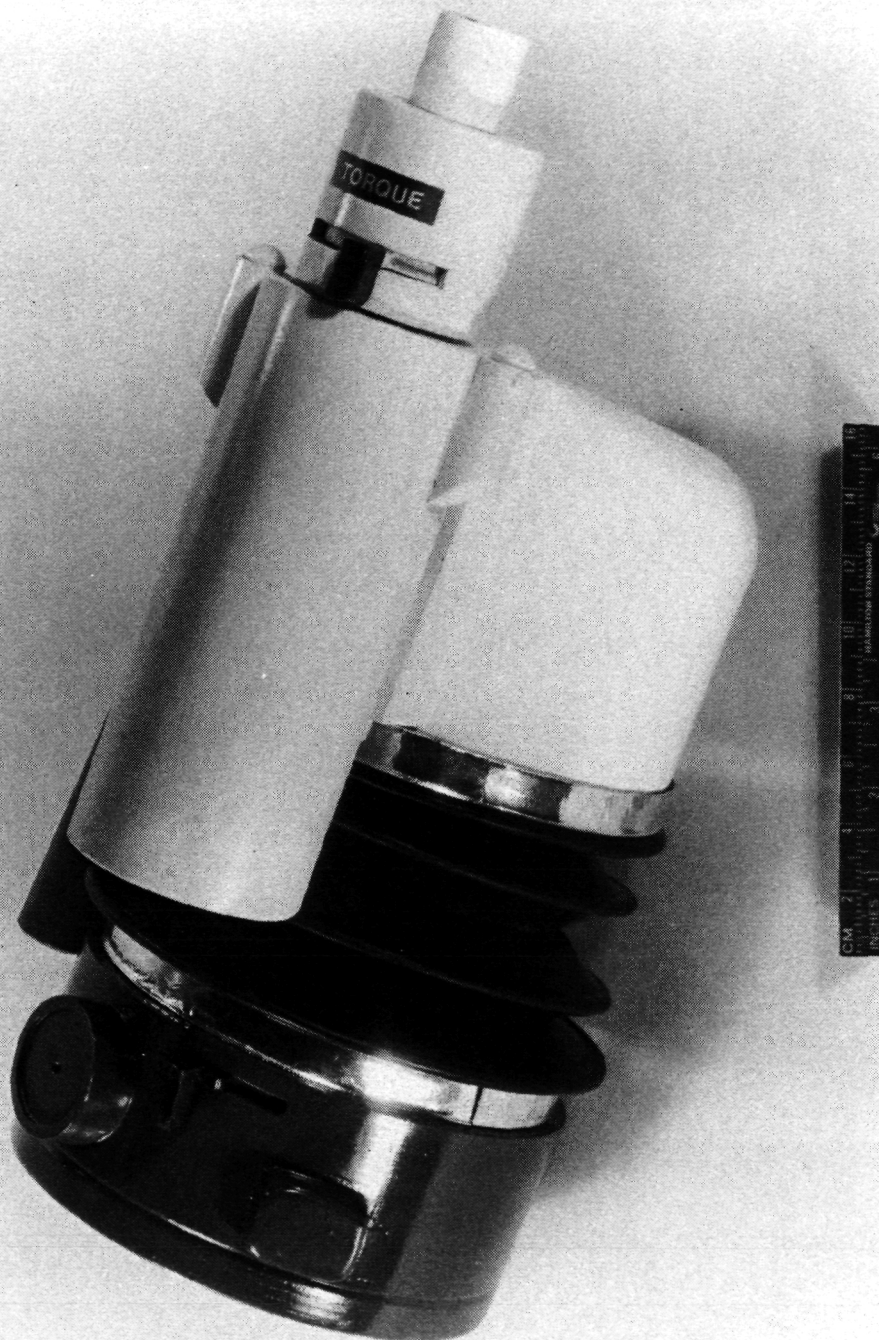


FIGURE 4-1  
PAGE REMOVABLE HOUSING CONCEPT

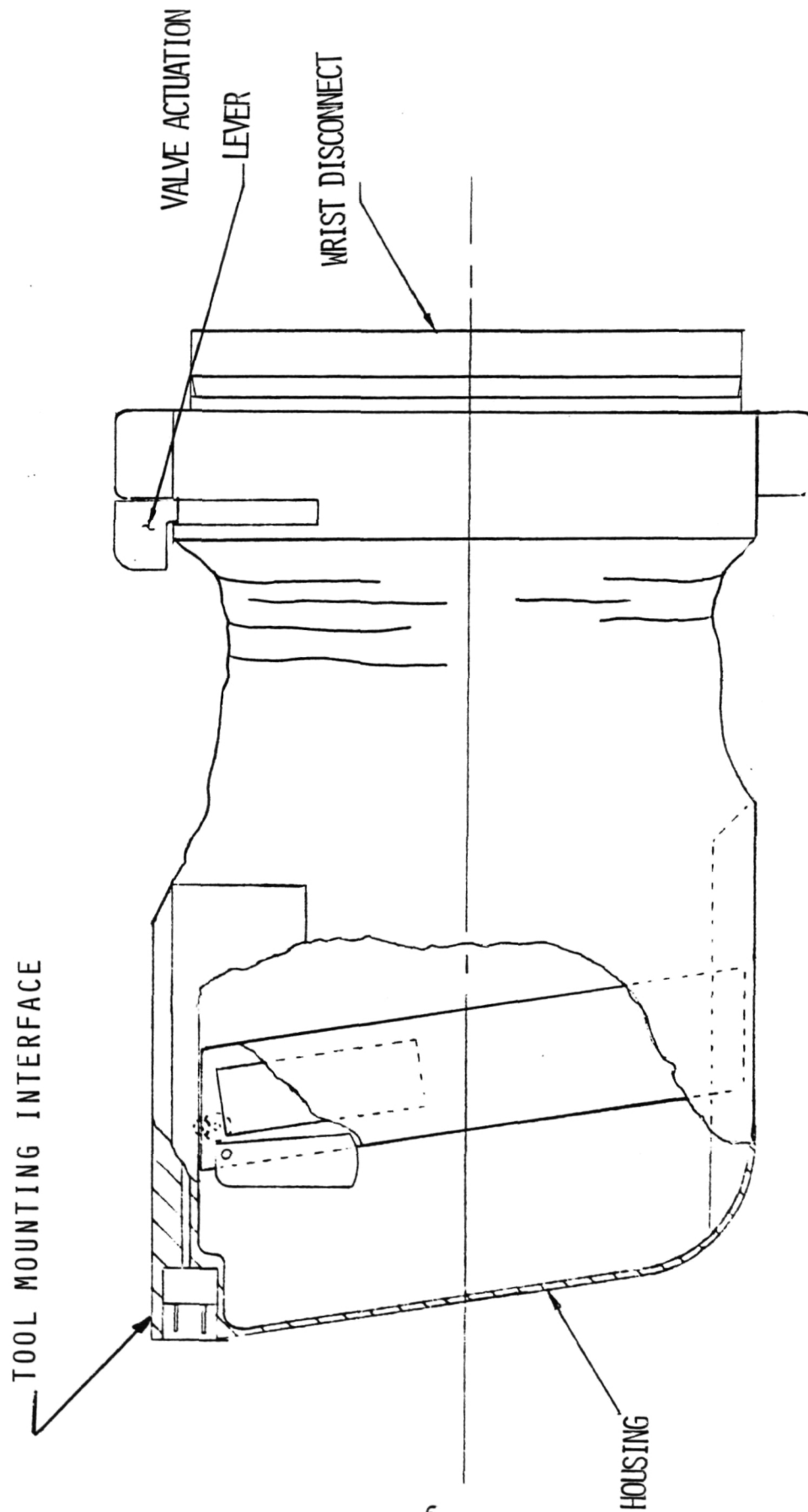


FIGURE 4-2  
PAGE REMOVABLE HOUSING



FIGURE 4-3  
PAGE ADAPTED GLOVE #1



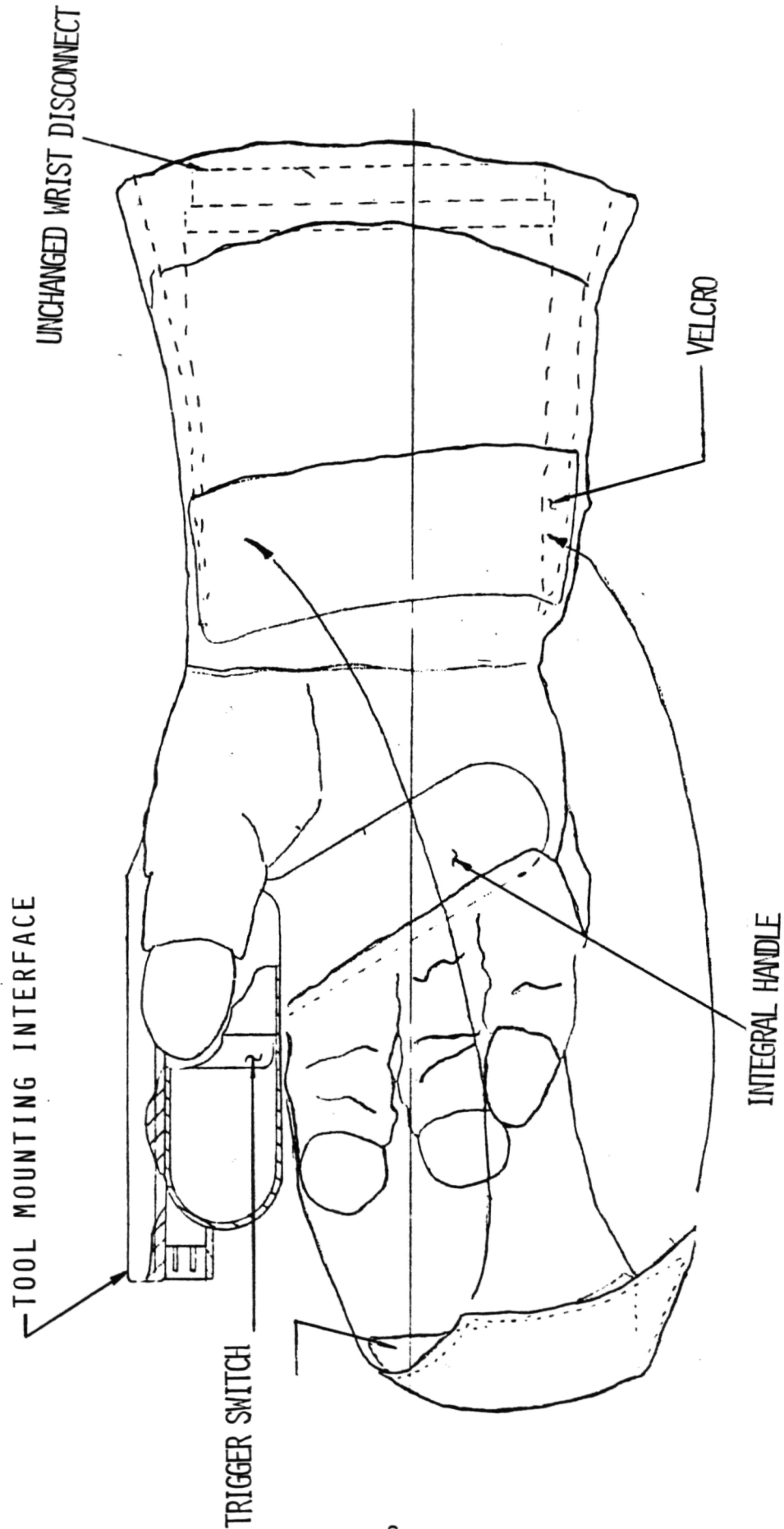


FIGURE 4-4  
PAGE ADAPTED GLOVE #1

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FIGURE 4-5  
ENCLOSED INDEX FINGER AND HANDLE TRACK

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FIGURE 4-6  
TOOL MOCKUP MOUNTED IN GLOVE WITH INTEGRAL TRIGGER FINGER

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FIGURE 4-7  
ADAPTED GLOVE #2





FIGURE 4-8

TOOL MOCKUP MOUNTED TO ADAPTED GLOVE #2



### Acoustic Feedback Concepts (continued)

- Sound transmission through a disconnect at the wrist
- Sound transmission quality at 4 psia
- Conversion of a pressure pulse to an electrical pulse for integration into the EMU audio system

The other concepts for acoustic feedback relied on piezoelectric elements mounted in the glove. The piezoelectric film PVDF was evaluated in a number of mounting techniques to determine its suitability for use as a glove mounted acoustic pickup. The film performed well, however, mounting electrical leads to the film proved to be difficult. Several accelerometers were also evaluated and the Endevco 2250A was finally selected based on its small size and high sensitivity (approximately 10.5 mV/g). This accelerometer operates on the same principle as the piezoelectric film but has the advantages of being pre-packaged and containing an integral pre-amplifier which reduces noise.

The integral amplifier requires a low power (5 mA @ 18 VDC) supply to provide a suitable signal for amplification through the audio amplifier. A Radio Shack 1 Watt audio amplifier was used to drive a set of headphones for the pre-prototype hardware.

As the accelerometer is mounted outside the bladder and beneath the TMG, it would normally be subjected to space vacuum. Testing was performed in a vacuum to determine the effects on sound quality. Although the sound clarity was diminished slightly in the vacuum, the vibration frequency was clearly discernible. Additional testing was performed to determine the location which provided the greatest signal. The selected location was the palm bar at the base of the index finger.

Issues still to be addressed are:

- electrical connection across the wrist joint
- interfacing with the EMU audio system
- volume control and on/off switch

### Generic Control

With the modified glove concepts set aside, several techniques were investigated for reducing hand fatigue by sensing finger position and using this signal to control motor speed or other control functions. The basic approach was to reduce the amount of finger travel required to obtain the equivalent of full travel on the tool trigger, thereby eliminating or at least greatly reducing the effort associated with flexure of the index finger in a pressurized EVA glove. The most promising technique was a strain gauge mounted on a flexible strip inside the glove. Flexure of the finger would cause a change in resistance in the strain gauge. This resistance could be used to vary a signal to the motor controller and thereby change motor speed. Two major problems were encountered with this concept:



### Generic Control (continued)

- 1) The strain gauge resistance would not return to the same value, so a zero point could not be established.
- 2) Locating the gauge on a strip that did not make finger flexure more difficult while simultaneously limiting the maximum strain to the gauge to prevent damage was unsuccessful.

Another concept replaced the stress strip with a piece of conductive foam which was supposed to change resistance as pressure was exerted. The problem with the conductive foam is that the change in resistance is very low in relation to the original resistance which causes the foam to be excessively sensitive. This concept was not studied any further.

### Power Tool Design

The development of the power tool was broken down into individual components and a trade study used to select the most suitable concepts for the assembly. The tool was broken down into the following details:

- Motor
- Speed control
- Gearing
- Torque limiting clutch
- Motor

Based on speed and torque requirements, motor size was established at 1/10 to 1/8 horsepower. Several motor types were considered including a brush permanent magnet motor, a brush shunt wound motor, and a brushless motor. Both brush motor types have limited life due to brush wear, especially in a vacuum and are also more difficult to cool since the rotor windings make limited contact to the housing via shaft bearings. The brushless motor has the benefit of superior thermal characteristics as well as long life due to the absence of brushes. The only negative feature of the brushless motor is the required added volume for control electronics. The brushless motor was selected for use in the PAGE power tool.

- Speed Control

In order to control motor speed, power to the motor must be controlled. Although rheostats are a common technique, they are relatively inefficient since they dissipate part of the available power as heat. The use of rheostats is considered unacceptable, especially when a battery may be the source of power. Two other techniques were investigated, Gearing, which has limited control capability but optimizes motor efficiency, and Pulse Width Modulation (PWM) which provides precise

control at a nominal efficiency. Proper gearing to operate in the modes of drilling (high speed) and torquing (low speed) combined with the capabilities of PWM for variable speed creates an efficient motor speed control system.

- Gearing

Several decisions had to be made regarding the gearing in the power tool. The first was whether to reduce the motor down to drilling speed only and provide a modular attachment for further reduction (torquing), provide two output shafts each running at different speeds, or provide a single output shaft with two selectable speed ranges. The single output shaft/two speed range gearing was selected.

The other concern was whether to generate reciprocating motion as an integral part of the tool or to provide this motion via a modular attachment. As this reciprocating motion was considered a "limited use" feature, it was decided that the concept of a modular attachment would reduce both the tool complexity and vibration.

- Torque Limiting Clutch

Two types of torque limiting clutches were investigated, magnetic and ball detent. The magnetic clutch had a wear advantage over the ball detent clutch as there is no contact between the magnet sets, however in order to be capable of maintaining 5-10 Ft.lbs at 50 RPM, the size of this magnetic clutch becomes prohibitively large. The ball detent clutch is a proven design used in many industrial/commercial applications and, except for wear, is far superior to the magnetic clutch.

- Hand Fatigue

While performing some grip evaluations at 4 psid, it was noted that much of the hand fatigue was due to trying to relax the index finger for trigger actuation while maintaining a firm grip with the thumb and other three fingers. If the three fingers could be held close to the grip, the grip would require less effort to maintain, thus reducing hand fatigue. A sheet metal guide was fabricated to hold the glove hand around the tool handle. As this guide had to allow for easy ingress/egress, it has some clearance which can be adjusted for various glove sizes by bending open or closed, based on personal preference.





V. PAGE PRE-PROTOTYPE TOOL & ACOUSTIC FEEDBACK

- Tool Mechanical

The PAGE Pre-Prototype Tool consists of a brushless DC motor operating at 24 VDC and at a speed of approximately 9000 RPM. Photos of the tool appear in Figures 5-1 and 5-2. Speed reduction is accomplished by two planetary gear sets each with 11:1 ratios. A sliding collar is used to engage or bypass the second reduction thereby selecting torquing mode (low range - 75 RPM max.) or drilling mode (high range - 800 RPM). The torque limiting clutch is engaged in the low speed range only. Torque is increased by turning the knurled collar in the direction indicated on the housing and can be varied from 0 to 10 Ft.lbs. A removable torque handle is provided to react high torques.

- Tool Electrical

Motor direction is controlled by a push-on/push-off switch mounted on the left side of the tool above the handle (ref. to PAGE Electrical Schematic Figure 5-3). Motor speed is controlled by Pulse Width Modulation (PWM). The resistance of the trigger-activated slide potentiometer is read by the PWM circuit. The output of the PWM circuit increases in duty cycle as the trigger is depressed. This circuit is connected to a logic inhibit on the drive board which permits power application to the motor when the PWM output signal exceeds approximately 5 VDC.

The motor control electronics, Pulse Width Modulation circuit, and constant current supply for the acoustic pickup are contained in an electrical box. An eight foot harness connects the power tool to the electrical box. Other inputs to the box are the glove mounted accelerometer input and the 24 VDC input from a customer furnished power supply which should be rated at 10 amps minimum.

- Acoustic Feedback

The acoustic feedback portion of the PAGE Pre-Prototype hardware consists of a glove-mounted accelerometer which transmits electrical signals to an audio amplifier through a coaxial cable. These signals are amplified by a 1W audio amplifier and monitored on a set of headphones.

The coaxial lead from the accelerometer also carries the constant current supply from the electrical controller. This energizes the pre-amplifier in the accelerometer and provides a stronger, cleaner signal to the audio amplifier.

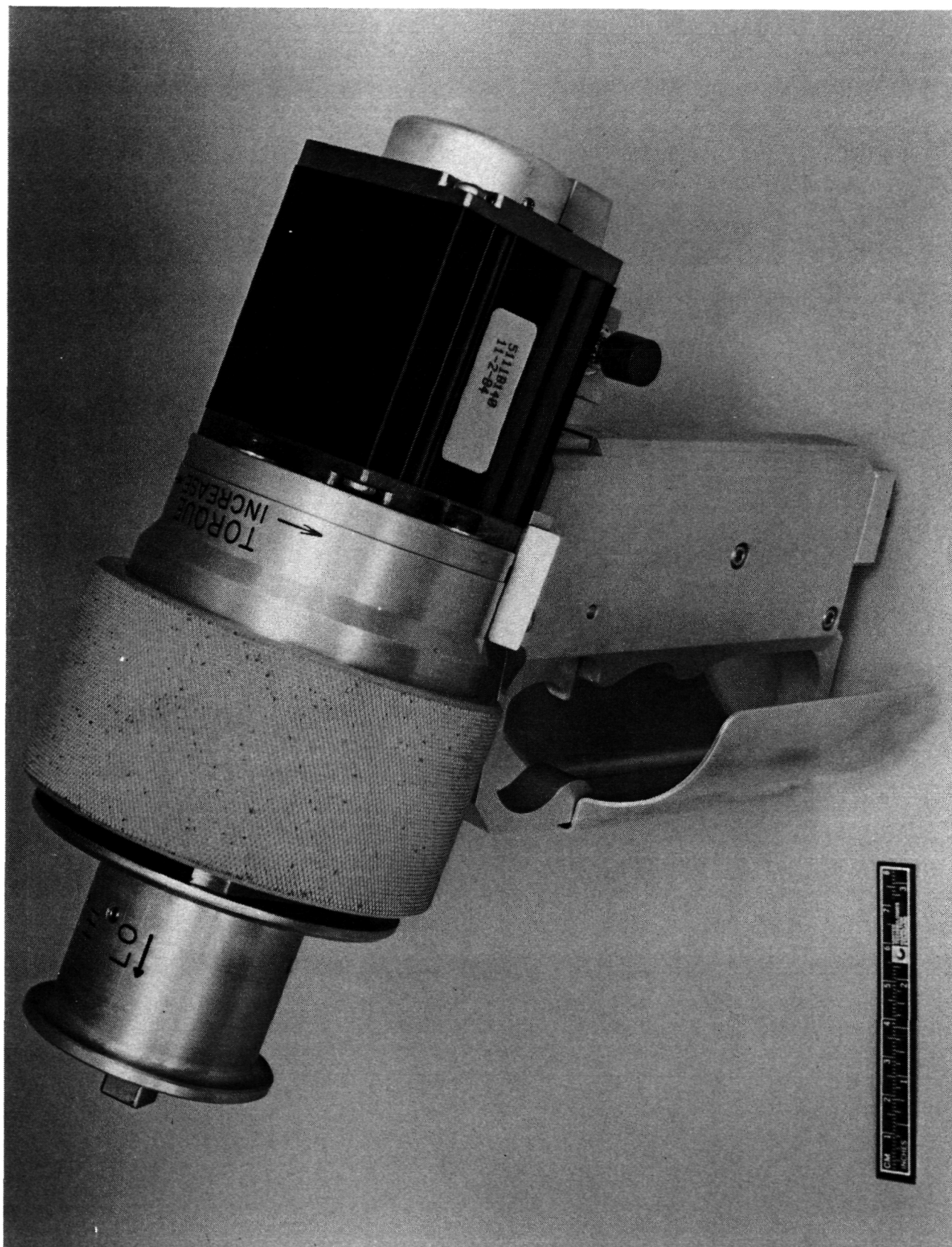


FIGURE 5-1  
PAGE POWER TOOL

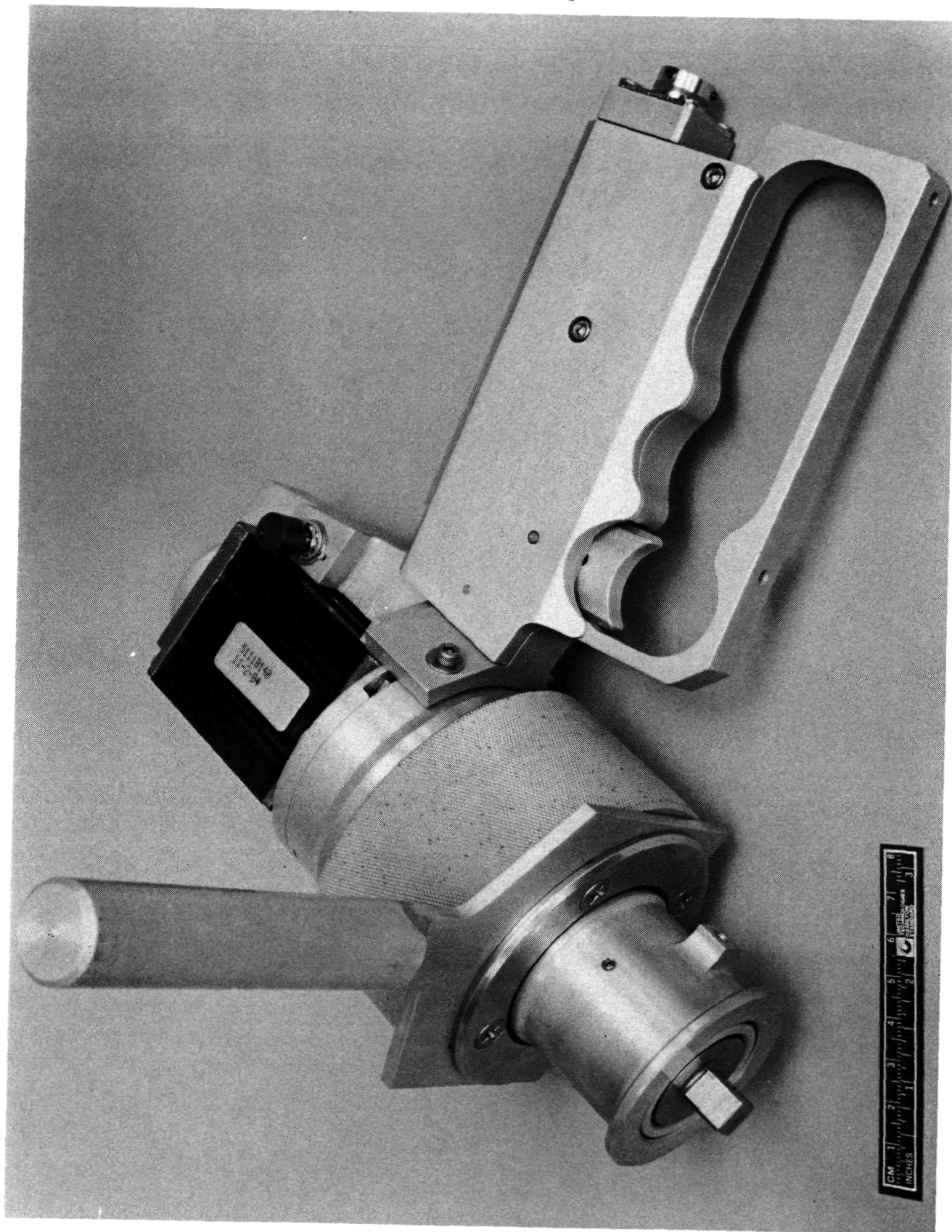


FIGURE 5-2  
PAGE POWER TOOL WITH TORQUE BAR

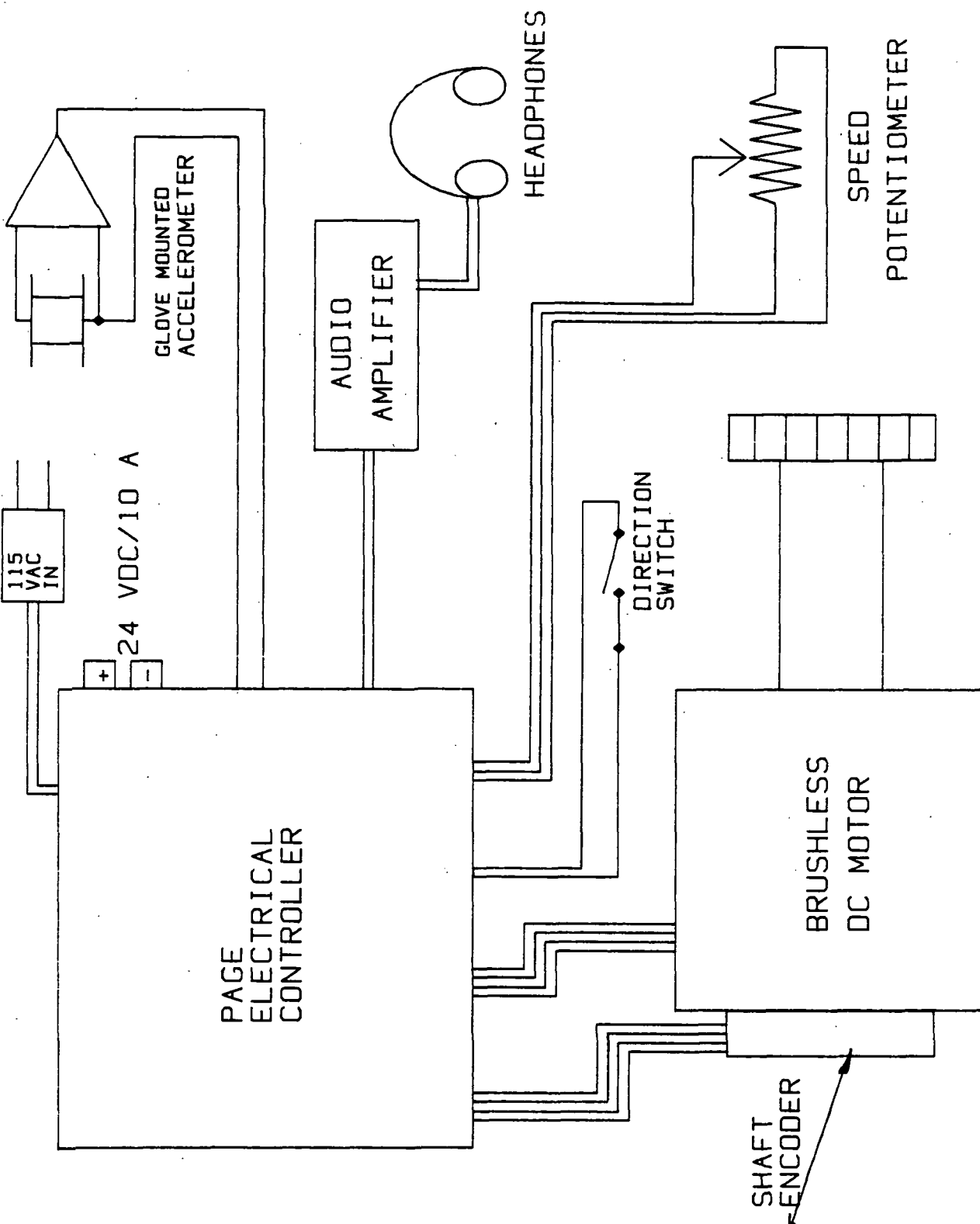


FIGURE 5-3  
ELECTRICAL SCHEMATIC



- Tool Performance

Testing was performed on the brushless DC motor as well as the tool assembly. Due to limitation of test equipment, the torque/speed curves are based on theoretical curves from the motor manufacturer with actual data indicated as points (ref. Figure 5-4). Figure 5-5 shows motor speed versus PWM duty cycle with the tool unloaded in the low speed range. Output shaft speed can be calculated by dividing motor speed by 121.

The tool was designed to provide an output torque of 10 Ft.lbs which is twice the original contract requirement. This output was verified during testing and while theoretical motor performance curves suggest that the motor and geartrain may be able to produce as much as 20 Ft.lbs, the clutch adjustment ring places increased bending loads on the spring retainer drive pins as higher torques are selected. Modification of the spring retainer could permit safe operation up to about 15 Ft.lbs.

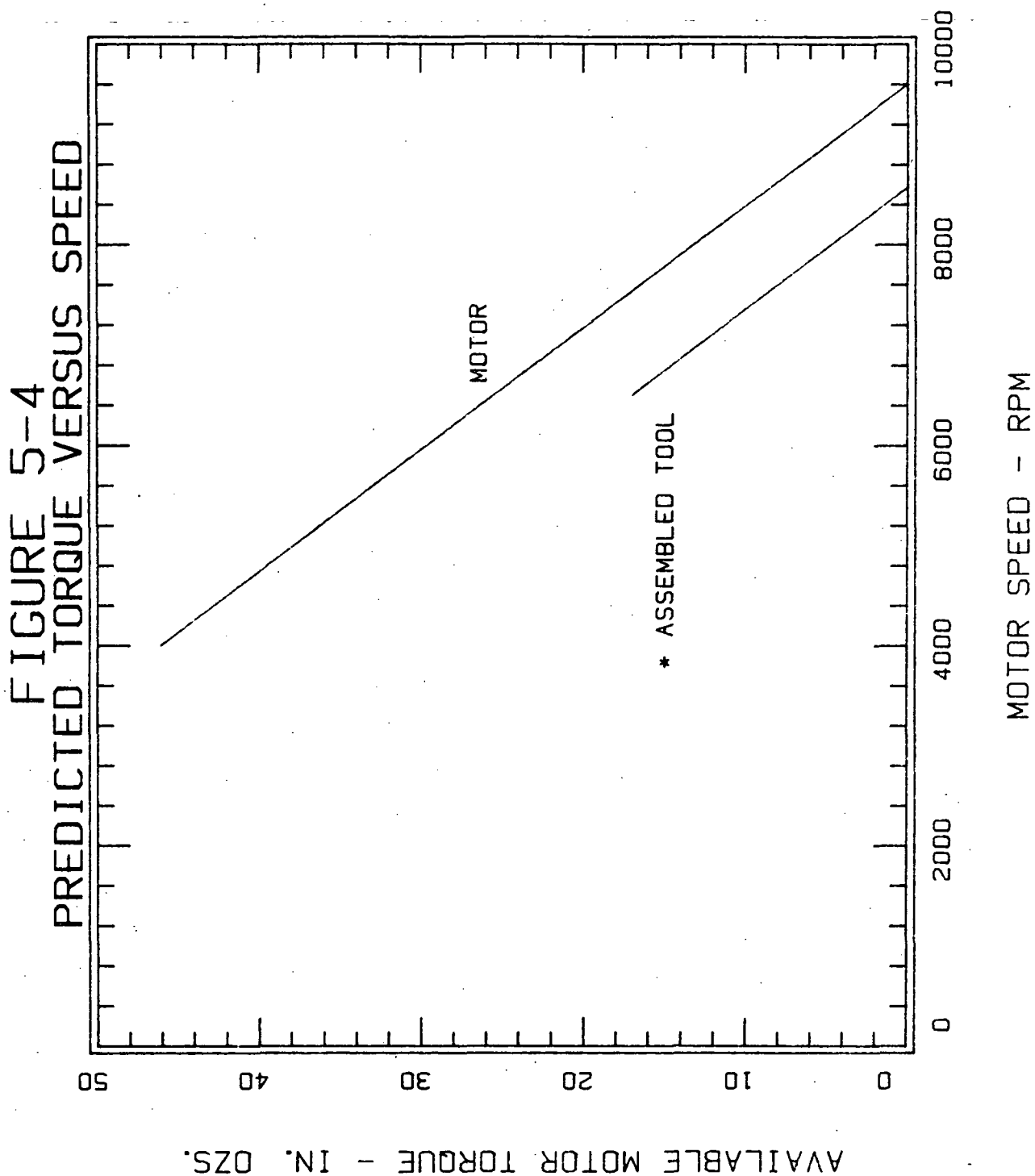
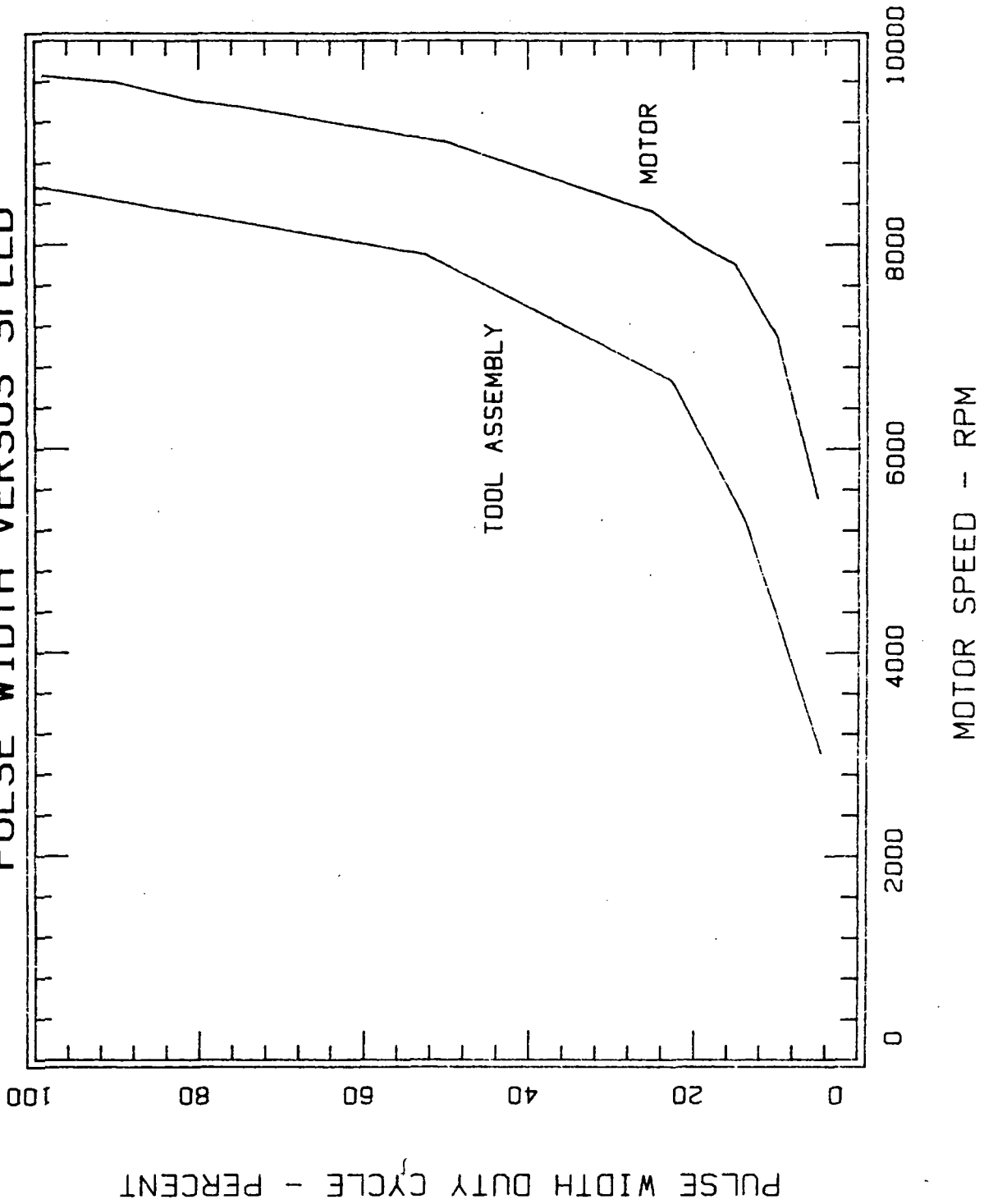




FIGURE 5-5  
PULSE WIDTH VERSUS SPEED

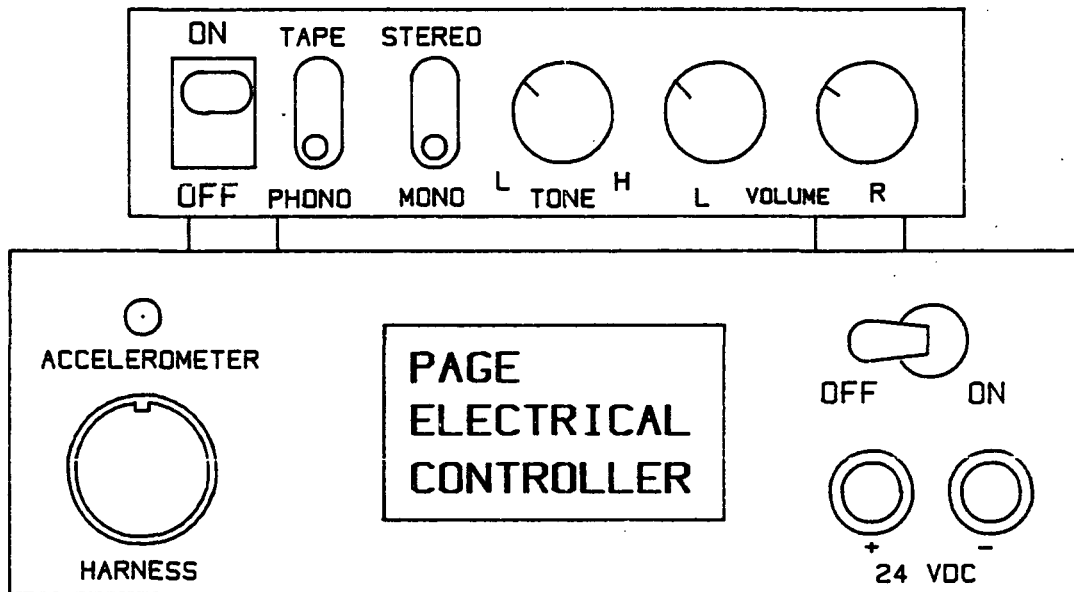




## VI. PAGE OPERATING INSTRUCTIONS

### REQUIRED SUPPORT EQUIPMENT:

- 24 VDC POWER SUPPLY WITH TWO BANANA PLUGS
- 115 VAC OUTLET



- 1- CONNECT 24 VDC POWER SUPPLY TO JACKS ON LOWER RIGHT OF FRONT PANEL
- 2- PLUG UNIT INTO 115 VAC OUTLET
- 3- CONNECT HEADPHONES TO 'Y' CABLE ON REAR OF AMPLIFIER
- 4- CONNECT COAXIAL ACCELEROMETER CABLE FROM GLOVE TO INPUT ON TOP LEFT OF FRONT PANEL
- 5- CONNECT POWER TOOL HARNESS TO HARNESS CONNECTOR ON FRONT PANEL AND TO POWER TOOL
- 6- TURN POWER SWITCH TO THE 'ON' POSITION

TOOL IS NOW READY TO OPERATE - ACOUSTIC SIGNAL FROM GLOVE CAN BE MONITORED THROUGH HEADPHONES AS MOTOR SPEED IS CHANGED